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# Impact of steel slag fertilizer on acid sulfate soils used for rice cultivation: a case study in An Giang Province, Vietnam

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**Abstract**

The study assesses steel slag fertilizer's effect on rice yield on acid sulfate soil in Vinh Phuoc village, Tri Ton district, An Giang province. A field experiment with three treatments was established by the randomized block method with three replications. The fertilizer dose applied in individual treatments was: (1) 3 tons/ha lime, (2) 3 tons/ha steel slag fertilizer, and (3) 3 tons/ha compost in the experiment. The farmers' practice fertilizer rate of 131 kg N + 41 kg $P_2O_5$ + 108 kg $K_2O$/ha was applied as the based treatment. Using steel slag fertilizer on acid sulfate soil at a dosage of 3 tons/ha in combination with inorganic fertilizers showed a tendency to improve soil chemical properties such as soil pH, EC, soil organic carbon (SOM) content, CEC, total P, available P, and exchangeable cations (K, Na, Mg) content. The slag fertilizer affected the growth of rice plants, thereby helping to increase the yield and yield components of rice compared to other treatments. The steel slag fertilizer has improved soil properties and rice yield, which was statistically significantly different from other treatments. However, total nitrogen and calcium exchange content have not improved considerably. Therefore, applying inorganic fertilizers combined with steel slag fertilizer is an appropriate solution to enhance soil nutrients and increase rice yield.

## 1. Introduction

According to Yildirim and Prezzi (2011) and Piatak et al. (2015), slag includes mixed elements will be better compounded because slag may consist of silicates, phosphates, regenerated carbonates, etc. The formation of slags in the reactions with furnace linings and fluxing limestone substances. The slag studied is a very heterogeneous type of waste. It is toxic and contains considerable quantities of heavy metals. In addition, the slag also includes the main components (Fe, Ca), secondary components (Al, Zn, Mn, Mg, Na, and K), and trace components (Pb, Cu, As, Ti, P, Ni, Ba, Co, Sr, Sb, Cr, Ga, Cr, Ga, Mo, V, Sn, Se, Zr, Ag, Ge, Rb, F, and Cl) (Kicińska and Wikar, 2021). It is known that slags have long been used as calcium fertilizers in many countries (Ito, 2015). Now that steel lag production has increased rapidly, and the steel industries are under pressure for eco-friendly and lag recycling. Steel slag considers to be a cost advantage over lime usage and has been used to replace lime to regulate soil acidity for agricultural production (Das et al., 2019).

Acidic soils are known to be difficult soils that contain $FeS_2$ and produce $H_2SO_4$. However, these soils are usually undamaged for cultivation when reduced or flooded. However, when exposed to air through drainage or digging, the $FeS_2$ reacts with $O_2$ and water to produce Fe compounds and $H_2SO_4$. In these soils, aluminum (Al) and iron (Fe) toxicity are relatively high, making the soil environment acidic, inhibiting plant growth, and leading to low and unstable yields (Ljung et al., 2009). In these cases, appropriate, the study considers the effective management of the potentially harmful effects of acid sulfate soils for agricultural use. Slag is the steel industry's by-product. Using steel slag fertilizers improves the rice soil's fertility and supports growth, enhances resistance to pests and diseases, and increases rice yields (Ning et al., 2014). In addition, steel slag is a cost-effective solution for in situ stabilizing heavy metals in soil (Gu et al., 2011). Plants can absorb heavy metals in the soil even at low concentrations through their roots and leaves. Kicińska and Wikar (2021) conducted an experiment involving cultivating contaminated lettuce and reference soil near industrial areas associated with mining and processing metal ores.

The study showed that these plants might accumulate metals with varying intensity; leafy and root vegetables are most sensitive. The uptake of Pb, Zn, and Fe is proportional to the content in the soil. It has been shown that Pb, Zn, Cd, and Cr are accumulated in excessive amounts in the lettuce leaves. Additionally, a particular resistance and tolerance to high contents of metals in the environment are characteristic of grass. Moreover, Kicińska and Gruszecka-Kosowska's (2016) study shows that the *Agrostis capillaries* (Ac) grass has developed permanent tolerance, particularly to high contents of Zn Pb and Cd. The Ac grass individuals also contain higher metal contents than those of the pioneer *Betula pendula* (Bp) birch tree, which suggests that the resistance mechanisms against pollution of grass varieties exceed those of trees. It is a sign of proper functioning of the tools that prevent excessive metal amounts from entering the cell metabolic system and of the presence of physiological barriers protecting the generative organs of trees. Therefore, the study aimed to evaluate the influence of steel slag fertilizers (with main macro-elements such as Ca, Si, Mg, S) on changing some soil chemical properties and improving rice yield on de-acidified soil in the Tri Ton district, An Giang province, Viet Nam as a case study.

## 2. Materials and methods

### 2.1. Research media

In the field, the experiment on active acid sulfate soil, deep appearance, with the *Umbric* horizon, named *Umbric Endo Orthi Thionic Gleysols* according to the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2015) in Vinh Phuoc village, Tri Ton district, An Giang province (Fig. 1).

The study included the 2017 Summer-Autumn and the 2018 Winter-Spring cropping seasons from April 2017 to March 2018. The OM 5451 rice variety used in the experiment had a growth period of 90–95 days. The amount of seed sown is 18–20 kg/1000 $m^2$. Fertilizers include urea (46% N), superphosphate (16% $P_2O_5$), KCl (50–60% $K_2O$), lime (90% CaO), compost (3.15% total nitrogen, 7.8% total P), and steel slag. Those contents are based on the soil analysis determinants and local recommendations. Steel slag fertilizer containing the main elements contained (in terms of oxides): calcium oxide (CaO) 44.3%, silicon dioxide ($SiO_2$) 13.8%, magnesium oxide (MgO) 6.4%, and sulfur (S) 0.07%.

### 2.2. Research Methods

#### 2.2.1. Experimental Design

The experiment designed in a completely randomized block includes three treatments and three replications. Each plot has an area of 25 $m^2$ (5m x 5m). The dosage of fertilizer in individual treatments shows in Table 1.

#### 2.2.2. Methods of sampling and analysis

The collection of soil samples at 0–20 cm layer before tilling and after harvesting at each study site. Each experimental lot took three soil samples from 1–1.5 kg/lot, mixed to get 1–1.5 kg. Then, the mixed soil samples of each treatment lot were taken at 1 kg.

For physicochemical analysis, were used the soil samples dried in the laboratory and ground through 2 mm and 0.5 mm sieves. The soil physicochemical properties analyzed include:

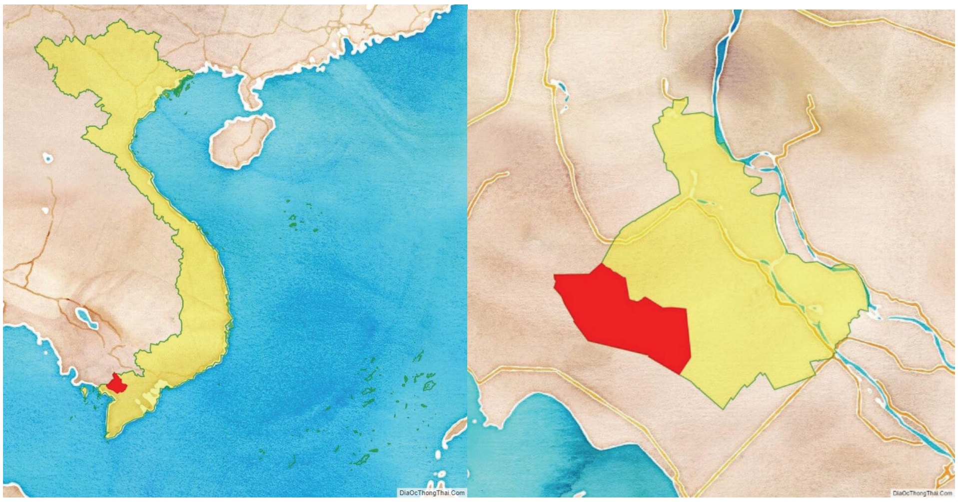

**Fig 1.** The study area location in An Giang province, Vietnam

**Table 1**
Fertilizer dosage for rice in the study site

| No | Treatments | Fertilizer dose per 1 ha |
|---|---|---|
| 1 | NT1 | 131 kg N + 41 kg $P_2O_5$ + 108 kg $K_2O$ + 3 tone lime |
| 2 | NT2 | 131 kg N + 41 kg $P_2O_5$ + 108 kg $K_2O$ + 3 tone steel slag |
| 3 | NT3 | 131 kg N + 41 kg $P_2O_5$ + 108 kg $K_2O$ + 3 tone sugarcane bagasse |

- before tilling: soil (pH), electrical conductivity (EC), cation exchange capacity (CEC), the content of organic carbon (OC), total nitrogen N and total phosphorus P, available phosphorus (mg $P_2O_5$/kg), exchangeable cations such as potassium($K^+$), sodium ($Na^+$), Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), aluminum ($Al^{3+}$) and soil texture;
- post-harvest: soil properties analyzed similar to before tillage, but without soil texture.

#### 2.2.3. Collected agronomic criteria

The total panicle/m² number; the total seeds number/panicle; the filled and unfilled grains/panicle ratio; average 1,000 grains weight, at a standard moisture content of 14% were calculated, in which:

- theoretical yield (ton/ha) = Panicles number/m² * Filled grains number/panicle * 1,000 grains weight * $10^{-4}$
- actual yield: Each treatment plot collected 05 points diagonally according to the experimental method in Vietnam, 3 m² each. Grains were cleaned, weighed, and measured immediately, reducing to a standard moisture content of 14%.

#### 2.2.4. Analytical methods

The following analytical methods were used:

- Soil pH ($pH_{H2O}$), electrical conductivity (EC): extraction of water, (ratio 1:2.5)
- Soil pH ($pH_{KCl}$): extracted with KCl solution (ratio 1:2.5)
- Exchangeable aluminum ($Al^{3+}$) (meq/100 g): extracted with 1N KCl, titrated with 1N NaOH, complexed with NaF, titrated with 0.01N $H_2SO_4$
- Cation Exchangeable Capacity (CEC) (meq/100 g): extracted with $BaCl_2$, exchanged with $MgSO_4$ solution, titrated excess $MgSO_4$ with EDTA solution
- Exchangeable cations are Calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) (meq/100 g): extracted with $BaCl_2$, measured on an atomic absorber
- Soil texture: based on the Robinson method according to the principle of Stocke's law and determining the grain grade based on the USD/Soil Taxonomy triangle
- Available phosphorus (mg $P_2O_5$/kg): Bray 2 method
- Total nitrogen (N%): digested with concentrated $H_2SO_4$ – $CuSO_4$ – Se, distilled Kjeldahl
- Total phosphorus (P%): digested with concentrated $H_2SO_4$ – $HClO_4$ and colorimetric measurement phosphomolybdate on the spectrophotometer
- The determination of soil organic carbon (%C) is based on the Walkley-Black chromic acid wet oxidation method.

#### 2.2.5. Data processing methods

Data were processed and calculated using Microsoft Excel software. Mean differences between treatments were analyzed by linear regression (GLM-General Linear Model), using SPSS statistics software and Duncan's test with differences at a 5% significance level.

## 3. Results and discussion

### 3.1. The soil properties of the study area

#### 3.1.1. Soil properties at the beginning of the cropping season

The soil analysis results of physical and chemical properties show that the pH in the topsoil (4.2) is the typical pH), the low organic carbon in the surface layer (3.64% C), and the average content in total nitrogen (0.196%) range of the acid sulfate soil in the Mekong Delta (Metson, 1961) (Table 2). It is low in total phosphorus (0.059%) and available phosphorus contents (6.33 mg P/kg) (Page et al., 1982). These soil properties vary depending on the organic quality and phosphate fertilizer application for crops. The exchangeable potassium ($K^+$) in the soil is deficient (0.0788 meq/100 g) (Kuyma, 1976). The exchangeable calcium ($Ca^{2+)}$ is low in the surface layer (3.34 meq/100 g) and deficient in exchangeable magnesium (1.36 meq/100 g). The sodium (Na) content is < 1 cmol (+)/kg, which indicates that the soil is not salinized or alkalized in the surface layer. The high exchange aluminum (6.68 meq/100 g) is potentially toxic to some plants, indicative of alkaline soil caused by Al toxin. The mechanical components of the surface layer consist of 8.98% sand, 39.88% silt, and 51.13% clay. In general, this is a group of soils with physicochemical and nutritional properties that are not favorable for plant growth planted in this soil due to alum properties.

**Table 2**
Some physico-chemical parameters of acid sulfate soil in Vinh Phuoc commune, Tri Ton district

| No | Soil characteristics | Value | No | Soil characteristics | Value |
|---|---|---|---|---|---|
| 1 | $pH_{H2O}$ (1:2.5) | 4,12 | 8 | Available P (mg P/kg) | 6,33 |
| 2 | $pH_{KCl}$ (1:2.5) | 3,37 | 9 | Exchangeable Kali (meq/100 g) | 0,0788 |
| 3 | $EC_{1,2,3}$ (mS/cm) | 0,238 | 10 | Exchangeable Na (meq/100 g) | 0,0568 |
| 4 | Organic matter (%) | 3,64 | 11 | Exchangeable Ca (meq/100 g) | 3,34 |
| 5 | CEC (meq/100 g) | 12,40 | 12 | Exchangeable Mg (meq/100 g) | 1,36 |
| 6 | Total N (%) | 0,196 | 13 | Exchangeable Al (meq/100 g) | 6,68 |
| 7 | Total P (%$P_2O_5$) | 0,059 | 14 | Texture (%) | |
| | | | | Sand, | 8,98 |
| | | | | Silt, | 39,88 |
| | | | | Clay | 51,13 |

### 3.1.2. The effect of steel slag fertilizers on soil properties of different treatments

3.1.2.1. Soil pH

The analysis results show that the pH value in all treatments tended to increase slightly compared to the beginning of the experiment. The highest was in the NT1 lime treatment (pH = 4.53). On the other hand, the treatments using NT2 steel slag and NT3 sugarcane bagasse fertilizer tended to increase almost equally (pH = 4.36 – 4.38). According to many scientists studying rice soil's chemical properties, optimal pH ranges from 5.0 to 6.5, which means that none of the used treatments made the soil pH optimal for rice (Table 3).

3.1.2.2. Total N (%)

The plant partly absorbs nitrogen; the rest can be lost through nitrate leaching or volatilization of ammonia and nitrate reduction products. Therefore, total nitrogen at the end of the crop was less volatile than at the beginning of the season, and there were treatments with a decreasing trend in nitrogen content. Through the analysis results, nitrogen content at the beginning of the crop was 0.196 %, considered low (Metson, 1961). Although this soil property did not significantly change at the end of harvest, the liming treatment increased (0.203% N). In contrast, steel slag and sugarcane bagasse compost treatment tended to decrease. Thus, compost of sugarcane sludge and steel slag has not improved the soil's total nitrogen, but liming fertilizer results in high total nitrogen on acidic soils. The cause may be because lime helps reduce soil acidity, creating favorable conditions for microorganisms to decompose organic matter to produce total nitrogen.

3.1.2.3. Total phosphorus (% P) and available phosphorus (mg $P_2O_5$/kg)

The analysis results show that the total phosphorus content at the beginning of the crop is 0.059%, which is considered poor in phosphorus (Le Van Can, 1978). At the end of the season, this soil property did not have a big difference between treatments. However, it tended to increase compared to the beginning of the season. Total phosphorus in the liming treatment tended to increase the highest with 0.087%. It shows that liming helps release phosphorus from the fixation by $Fe^{2+}$, $Al^{3+}$ in the soil, improving total phosphorus on acid soils.

The available phosphorus content in the soil at the beginning of the crop was 6.33 mg P/kg (Bray 2), which was assessed as low (Page et al., 1982). However, there was a difference in available phosphorus between treatments at the end of the season. The liming with 5.99 mg P/kg tended to decrease compared to the beginning of the crop. In comparison, steel slag and sugarcane bagasse treatment improved available phosphorus in the soil (10.5 mg P/kg and 11.4 mg P/kg, respectively). The results can be due to the addition of compost with sugarcane bagasse (7.8% of total P as in above), significantly increasing the available phosphorus content in the soil, tended to increase. The organic fertilizers help promote microbial activity and mineralize organic and insoluble phosphorus compounds faster and more intensely, then improve the available content in the soil (Guong et al., 2010).

3.1.2.4. Soil organic carbon (% C)

The analysis results showed that the soil organic carbon content in the soil between treatments (ranging from 4.22–4.44% C) tended to increase compared to the beginning of the crop (3.64% C). These can be due to the low pH value of acid sulfate soil, which limits the mineralization ability of soil microorganisms towards plant residues, leading to the high organic carbon content in the surface layer (Guong et al., 2016)

3.1.2.5. Exchangeable calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) (meq/100 g)

Experimental results showed that $Ca^{2+}$ increases only after lime application, and $Mg^{2+}$ in the treatments increase at the crop's end. Still, the $Ca^{2+}$ value in the steel slag fertilizer treatment tended to decrease. Probably, due to the application of a large amount of steel slag with components CaO (44.3%) and MgO (6.4%) resulting, the effective panicle number/$m^2$ tended to increase but was not different from the other treatments (Table 4). Hence, the amount of Ca supplied to the soil was sufficient for the plants. However, sometimes, plants must take some Ca to meet growth and development needs.

3.1.2.6. Exchangeable potassium ($K^+$) (meq/100 g)

The analysis results show that the amount of exchangeable potassium in the soil at the beginning of the crop is 0.0788 meq/100 g, which is very low (Kyuma, 1976). However, the $K^+$ value in the treatments did not differ significantly. On the contrary, it tended to increase compared to the beginning of the experiment. Therefore, it could be due to supplementing a large $K^+$ (108 kg/ha) in mineral fertilizers.

**Table 3**
The soil chemical properties at the beginning and end of the crop

| Treatments | $pH_{H2O(1:2.5)}$ | $EC_{1:2.5}$ (mS/cm) | CEC meq/100 g | OM % | $N_{ts}$ % | $P_{ts}$ % | $P_{avai}$ mg/kg | $K_{ex}$ meq/100 g | $Na_{ex}$ | $Ca_{ex}$ | $Mg_{ex}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Beginning | 4.12 | 0.24 | 12.4 | 3.64 | 0.20 | 0.06 | 6.33 | 0.08 | 0.06 | 3.34 | 1.36 |
| $NT_1$ | 4.53 | 0.23 | 12.9 | 4.41 | 0.20 | 0.09 | 5.99 | 0.17 | 0.16 | 4.34 | 1.79 |
| $NT_2$ | 4.38 | 0.26 | 13.0 | 4.44 | 0.19 | 0.07 | 10.5 | 0.17 | 0.17 | 3.13 | 1.76 |
| $NT_3$ | 4.36 | 0.23 | 12.9 | 4.22 | 0.17 | 0.07 | 11.4 | 0.18 | 0.19 | 3.34 | 1.76 |

Note: Treatments as in Table 1

**Table 4**
Rice yield and yield components in the study site

| Treatments | Summer-Autumn Season | | | | | | Winter-Spring Season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Effective panicle /m$^2$ (panicle) | Grains number/ panicle (Seeds) | Filled grans rate (%) | 1,000 grains (g) weight) at 14% | Theoretical yield (ton/ha) | Actual yield (ton/ha) at 14% | Effective panicle /m$^2$ (panicle) | Grains number/ panicle (Seeds) | Filled grans rate (%) | 1000 grains (g) weight) at 14% | Theoretical yield (ton/ha) | Actual yield (ton/ha) at 14% |
| NT1 | $294^{a}$ | $80.6^{a}$ | $86.7^{a}$ | $25.0^{a}$ | $5.14^{a}$ | $4.12^{a}$ | $417^{a}$ | $77.8^{b}$ | $90.3^{a}$ | $25.3^{a}$ | $5.41^{b}$ | $4.37^{b}$ |
| NT2 | $352^{a}$ | $75.1^{a}$ | $87.6^{a}$ | $24.4^{a}$ | $5.62^{a}$ | $4.28^{a}$ | $445^{a}$ | $84.0^{a}$ | $90.6^{a}$ | $24.8^{a}$ | $7.40^{a}$ | $5.08^{a}$ |
| NT3 | $296^{a}$ | $90.9^{a}$ | $87.6^{a}$ | $24.9^{a}$ | $5.67^{a}$ | $4.21^{a}$ | $368^{b}$ | $82.2^{ab}$ | $90.5^{a}$ | $25.1^{a}$ | $6.88^{a}$ | $4.59^{ab}$ |
| *CV (%)* | *8.44* | *12.3* | *0.46* | *1.17* | *8.29* | *12.66* | *4.34* | *2.86* | *0.97* | *2.11* | *7.70* | *4.87* |
| *F* | *ns* | *ns* | *ns* | *ns* | *ns* | *ns* | * | * | *ns* | *ns* | * | * |

Note: Treatment as in Table 1

3.1.2.7. Exchangeable sodium ($Na^+$) (meq/100 g)

The amount of exchangeable sodium ($Na^+$) in the soil before the experiment was 0.0568 meq/100 g, which was very low (Kyuma, 1976). Therefore, the $Na^+$ content increased in all treatments compared to the beginning because potassium replaced the cations such as sodium, calcium, and magnesium in the absorption complex when potassium fertilizers are applied to the soil. Therefore, the plant partly absorbs $Na^+$, and the rest leaches into the water. However, $Na^+$ released was still in the dry soil when sampling, causing the $Na^+$ content to increase.

3.1.2.8. Cation Exchange Capacity – CEC (meq/100 g)

The soil CEC content of 12.4 meq/100 g is considered low (Landon, 1984). However, CEC in the treatments did not differ and tended to increase compared to the beginning of the crop. The cause may be the addition of organic fertilizers, lime, and steel slag as recommended, which increased the CEC index in the soil.

### 3.1.3. The effect of steel slag fertilizer on rice yield and yield composition on acid soil

3.1.3.1. Rice yield components

According to Table 4 and Fig. 2, the rice yield composition between treatments in the Summer-Autumn crop did not differ significantly, leading to no difference in the theoretical yield and the actual yield. Similarly, in the winter-spring cropping season, the plant height, filled/unfilled grains, and average 1,000 grains weight were not different between treatments. Still, there was a significant

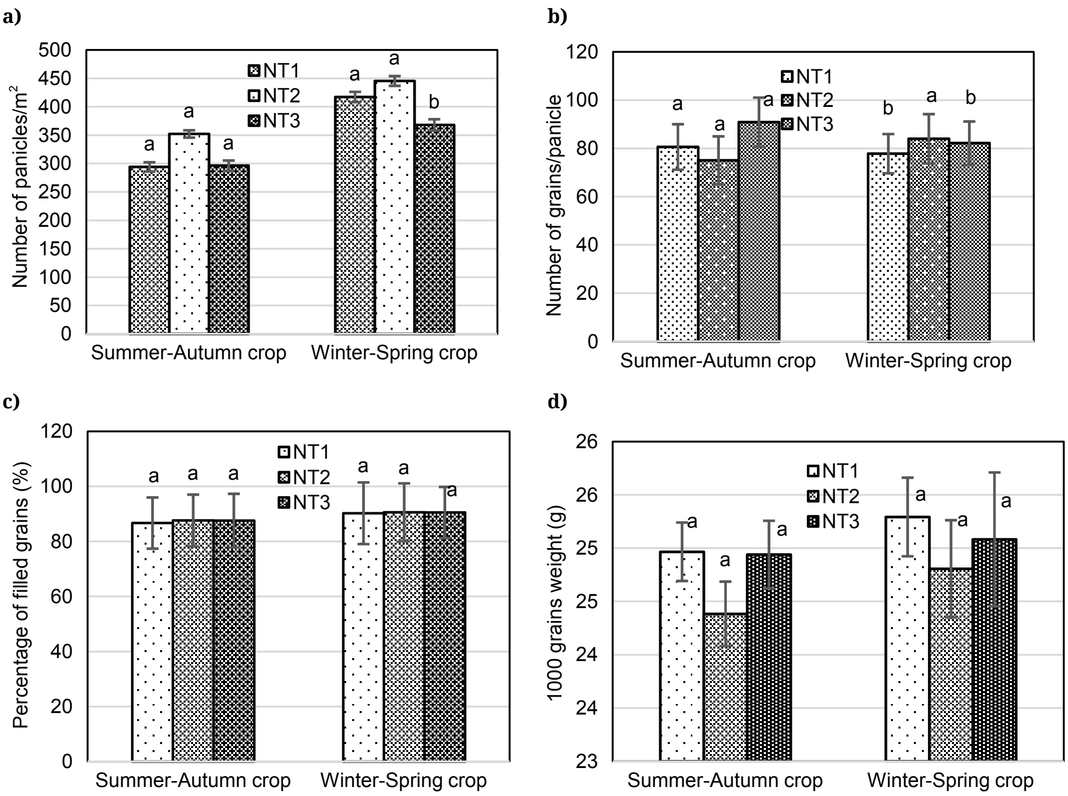


**Fig 2.** Rice yield component (a) Number of panicle/m$^2$, b) Number of grain/panicle, (c) % of filled grain, (d) 1,000 g grain weight of different treatments at two seasons in the study site

Note: Treatments as in Table 1.

difference in yield components. Therefore, there is a difference between theoretical yield and actual yield between treatments.

3.1.3.2. Number of panicles/m$^2$

The panicles/m$^2$ ranged from 294 to 352 in the Summer-Autumn crop and from 368 to 445 in the Winter-Spring season. The panicle/m$^2$ in the steel slag treatment was the highest at 352 panicles in the Summer-Autumn and 445 in the Winter-Spring cropping seasons. The results show that the application of steel slag is practical on acid sulfate soils concerning the number of panicle/m$^2$. The reason may be that steel slag fertilizers could increase soil pH and provide minerals such as Ca and Mg and many trace elements to improve soil fertility and then increase the number of tillers and effective tillers/plants.

3.1.3.3. Number of grains/panicle

The number of spikelets/panicles in the steel slag treatments and compost was significantly different from that of the liming treatment. Specifically, in the winter-spring crop, the steel slag treatment had the highest spikelets per panicle of 84.0, followed by the composting treatment with 82.2. On the other hand, the number of spikelets/panicles of liming treatment finally reached the lowest with 77.8 spikelets/panicles. The reason may be that the soil pH improved, and high Si was supplied from steel slag fertilizer (13.8% $SiO_2$), which is sufficient for the reproductive stage of rice (Nguyen, 2008).

3.1.3.4. The filled grains percentage

Depending on the number of the flower per panicle, the physiological characteristics of rice, and influenced by weather conditions, often too many flowers will lead to a low grains number per panicle. The filled grains percentage ranged from 86.7 to 87.6% (Summer-Autumn crop) and from 90.3% to 90.6% (Winter-Spring crop). The steel slag fertilizer treatment tended to have a higher filled grains number. Still, there was no significant difference compared to other treatments. Because the steel slag fertilizer application added Ca, Mg, Si, S, and other trace elements to the acidic soil for better rice plant growth, increasing the grain production process, then reducing unfilled grains.

3.1.3.5. Weight 1000 grains

The weight of 1,000 grains did not differ between treatments, ranging from 24.4 g to 25 g (Summer-Autumn crop) and 24.8 g to 25.3 g (Winter-Spring crop). Thus, it shows that the weight of 1000 grains depends significantly on the rice variety, while the cultivation technique has less influence on the 1000 grain weight.

3.1.3.6. Theoretical yield (ton/ha)

Rice yield is directly affected by the panicles number/m$^2$, grains number/panicle, filled grains percentage, and 1,000 grains (De, 2008). Therefore, the rice yield components in the Winter-Spring crop have many differences, leading to a statistically significant difference in theoretical yield.

3.1.3.7. Practical yield (ton/ha)

The yield reflects the availability of nutrients in the soil. Fig. 1 shows that the actual yield in the summer-autumn crop was no statistically significant difference between treatments. According to Fig. 3, there was no difference between yield components and average actual yield. Ranged from 4.12 to 4.28 tons/ha, the rice yield of steel slag fertilizer treatment did not significantly differ from others. Mineral fertilizer combined with steel slag fertilizer in the next Winter-Spring crop produced the highest rice yield of 5.08 tons/ha, and the lowest treatment was liming with 4.37 tons/ha. The steel slag fertilizer application provides the Ca, Mg, Si, S contents, and other microelements that significantly improve the rice yield composition. In addition, applying fertilizers with $Ca^{2+}$ neutralizes the soil acidic and quickly increases the soil pH value. It reduces the harm of aluminum, and iron toxicity (the cause of root poisoning), helping plants grow and give healthy growth and then high productivity.

## 4. Conclusions

The study identified steel slag fertilizer's effectiveness in neutralizing acid soil properties and improving rice yield and production, turning steel lags into a high-value-added product in sustainable agriculture. Using steel slag fertilizer on acid sulfate soil at a dosage of 3 tons/ha in combination with mineral fertilizers showed a tendency to improve soil chemical properties such as soil pH, EC, soil organic carbon, CEC, total P, and available P content, and exchangeable cations (K, Na, Mg). In addition, the steel slag fertilizer application also affected the rice plants' growth, thereby helping to increase the yield and yield components of rice compared to other treatments.

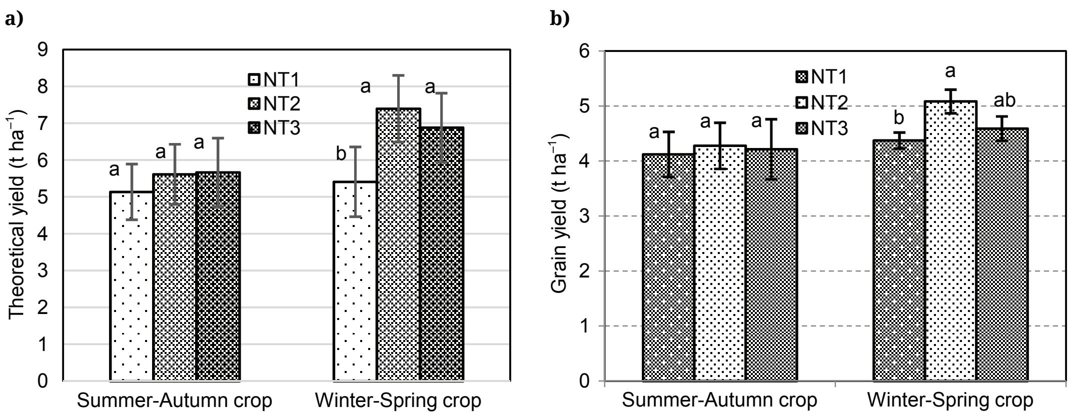


**Fig 3.** Theoretical (a) and Practical (b) rice yield of different treatments at two seasons in the study site (note: 'a' and 'b') represents the significant difference according to the treatment ($p < 0.05$); ns: no significant difference. The columns with the same letter are not significantly different 5%

It is necessary to study the effect of slag fertilizer on different soils. Besides, it needs to verify the quality of agricultural products to make recommendations on the appropriate dose of steel slag fertilizer for other crops.

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